California Environmental Protection Agency
Air Resources Board

Detailed California-Modified GREET Pathway for California Reformulated Gasoline (CaRFG)

Stationary Source Division

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The Staff of the Air Resources Board developed this preliminary draft version as part of the Low Carbon Fuel Standard Regulatory Process

The ARB acknowledges contributions from the California Energy Commission, TIAX and Life Cycle Associates during the development of this document

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These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner.

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SUMMARY

Pathway for California Reformulated Gasoline

A Well-To-Tank (WTT) Life Cycle Analysis of a fuel pathway includes all steps from crude oil recovery to final finished fuel. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together, WTT and TTW analysis are combined to provide a total Well-To-Wheel (WTW) analysis.

A Life Cycle Analysis Model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)[1] developed by Argonne National Laboratory forms the core basis of the methodology used in this document. The model however, was modified by TIAX under contract to the California Energy Commission during the AB 1007 process[2]. Using this model, staff developed a pathway document for CaRFG which was made available in mid-2008. Subsequent to this, the Argonne Model was updated in September 2008. To reflect the update and to incorporate other changes, staff contracted with Life Cycle Associates to update the CA-GREET model. This updated California modified GREET model (v1.8b) (December 2008 release) forms the basis of this document. It has been used to calculate the energy use and greenhouse gas (GHG) emissions associated with the production and use of California Reformulated Gasoline (CaRFG).

California Reformulated Gasoline (CaRFG) is a mixture of California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) and ethanol. For 2010, per the regulations of the Air Resources Board, an oxygenate such as ethanol must be blended into CARBOB and for the purposes of this document, a projected blending of ethanol with CARBOB to satisfy the 3.5% oxygenate requirement is used here.

Ethanol destined to be used as a blendstock in CaRFG requires blending with a denaturant. Typically, the denaturant added is gasoline (the GREET model default) but for this document, the denaturant is assumed to be CARBOB. Denatured ethanol is therefore anhydrous ethanol mixed with CARBOB. The denaturant level is usually between 2 to 4.75% (by volume) of gasoline blended with anhydrous ethanol but the CA-GREET model used for this document assumes 2.0% is used to blend with anhydrous ethanol. The CA-GREET model calculates CaRFG based on blending with denatured ethanol and these calculations are provided in this document (denatured ethanol is blended with CARBOB to achieve a 3.5% oxygen level as required by the ARB for 2010).

This document provides only the results of blending CARBOB with denatured ethanol. Complete details of WTW analysis for CARBOB and ethanol (for this document, the feedstock for ethanol is assumed to be from corn) are available as separate documents on the Low Carbon Fuel Standard website. The life cycle energy use and GHG emissions for CaRFG is based on weighted results for CARBOB and ethanol. This document essentially merges the WTW values proportionally and provides an aggregate WTW value for CaRFG. For detailed explanation, users are referred to the

[1] http://www.transportation.anl.gov/software/GREET/
[2] http://www.energy.ca.gov/ab1007/

individual pathway documents. Appendix A in this document provides blending calculations for CaRFG using the pathway information for CARBOB and corn ethanol. Note for this document, a land use change value of 35 gCO2/MJ has been applied. This is based on the draft analysis presented by staff for corn ethanol. Details of this is available in the corn ethanol pathway document.

The pathway for each blending component is shown in Figure 1. The results for each of the blending components are calculated based on each fuel being delivered as a pure component through its infrastructure. The CARBOB[3] WTT results are calculated as if pure CARBOB were delivered to the fueling station. Similarly, the WTT results for ethanol are calculated as if this component were delivered to the fueling station. The results for CaRFG are then calculated based on the energy weighted average. Detailed calculations are provided in Appendix A.

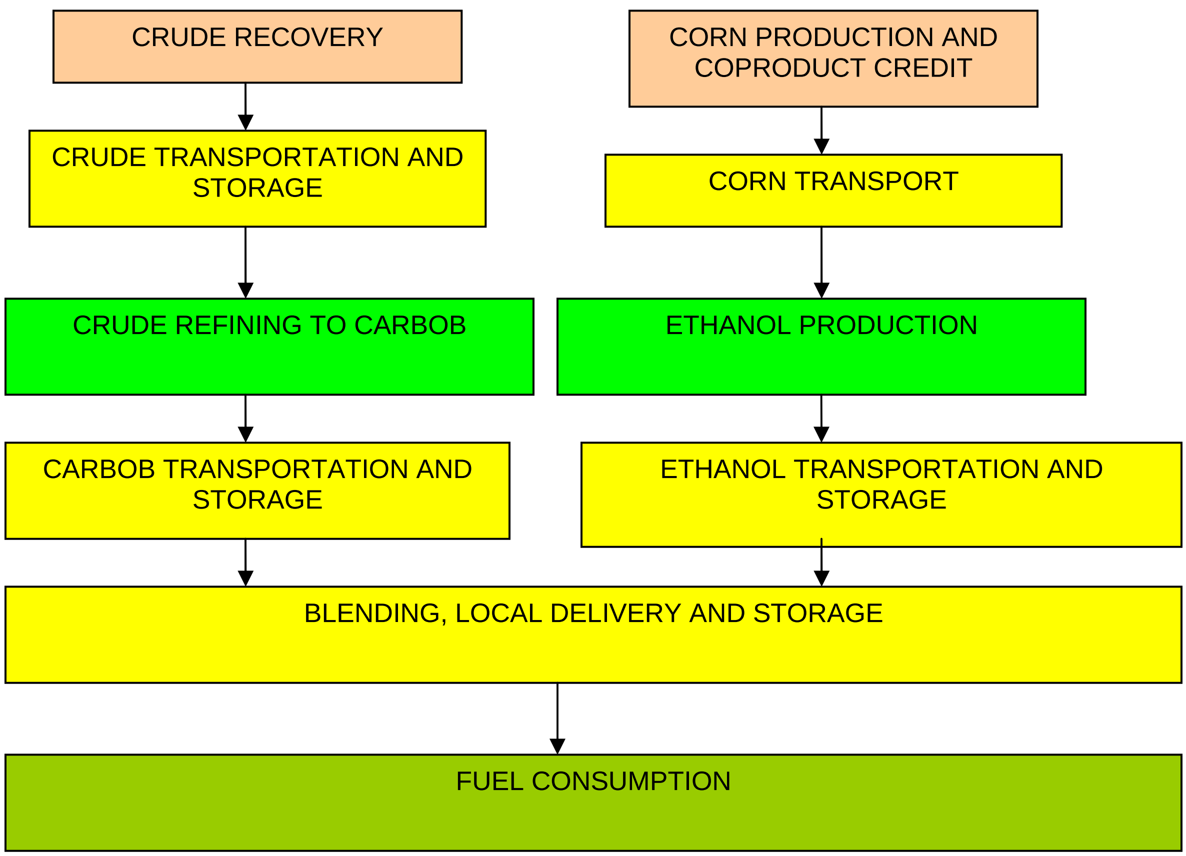

Figure 1. Pathway Components for Ethanol Blended with CARBOB.

[3] Note: CARBOB analysis uses average California crude. Ethanol used here is produced in the mid-western United States using a dry milling process, and transported to California. Complete details of the CARBOB and ethanol pathways are provided in separate documents.

Table A below summarizes the GHG emissions contributions from WTT and TTW based on an energy weighted average for CARBOB and corn ethanol. Detailed calculations are provided in Appendix A.

Note that average corn ethanol WTW values include a Land Use Change value of 35 gCO_2/MJ.

Table A. Well To Wheel Analysis for CaRFG and Blending Components

GHG Emissions (gCO_2e/MJ)	CaRFG
WTT CH_4	2.4
WTT N_2O	0.9
WTT CO_2	25.9
TTW $CO_2 + N_2O + CH_4$	68.5
Total WTW (gCO_2e/MJ)	**97.8**

Note: Due to rounding, values may not add up as shown in the table

APPENDIX A

1.1 GHG Emissions for CaRFG Pathway

This section provides details on combining the GHG emission components of CARBOB and corn ethanol. The energy fraction of each component is shown in Table 1.01. The 3.5% oxygen content of CaRFG is used to calculate the energy contribution of anhydrous ethanol to CaRFG. This is detailed in Table 1.02 which shows that ethanol contributes 6.5% on an energy basis to the total LHV of CaRFG. The lower heating value and carbon content of RFG is based on the volumetric fraction and heating value of its blending components. Table 1.01 also details the WTT CH_4, N_2O and CO_2 emissions for CARBOB, ethanol and the denaturant. It also provides TTW CO_2 emissions. These emissions are proportionally weighted to calculate the WTW GHG emissions for CaRFG. An additional component that is added is the tailpipe emissions of CH_4 and N_2O resulting from combustion of the fuel in a light duty vehicle. Details of CH_4 and N_2O tailpipe emissions are provided in Table 1.03.

Table 1.01 Details of Calculating WTW GHG Emissions for CaRFG

	CARBOB	**Ethanol**	**Denaturant (CARBOB)**	**CaRFG**
Lower Heating Value (Btu/gal)	113,300	76,330	113,300	
Volume % for blending	90.4%	9.4%	0.2%	n/a
Energy % for blending	93.3%	6.5%	0.2%	n/a
WTT CH_4 (gCO_2e/MJ)	2.5	2.1	2.5	2.4
WTT N_2O (gCO_2e/MJ)	0.1	11.9	0.1	0.9
WTT CO_2 (gCO_2e/MJ)	21.5	89.7	21.5	25.9
TTW CO_2 (gCO_2e/MJ)	72.9	0	72.9	67.7*
TTW CH_4 (gCO_2e/MJ)	0.16**	0	0	0.16
TTW N_2O (gCO_2e/MJ)	0.66**	0	0	0.66
Total WTW (gCO_2e/MJ)				**97.8**

** Corrections for CH_4 made here since CH_4 emissions are later added as tailpipe CH_4 emissions.*
*** These are from combustion emissions from CaRFG but have been listed under CARBOB. Also, these are total emissions and not weighted for CARBOB energy fraction when used in the rightmost column of the above table.*

Table 1.02 Calculation of Energy Content of Ethanol in CaRFG

Component	**Oxygen content (wt%)**	**Ethanol content**		
		Wt %	Vol %	Energy %, LHV
Ethanol	16/(46)= 34.8%			
CARBOB	3.5%	(3.5% * 46/16) = 10.06%	(10.06%/2988)/ [((1-10.06%) /2767)) + (10.06%/2988)] = 9.4%	(9.4%*76330)/ [((1-9.4%) * 113,300)+ (9.4%*76,330)] = 6.5%

Note: CARBOB density = 2,767g/gal, Neat ethanol density = 2,988 g/gal (both GREET default values)
Molecular weight of ethanol= 46 g/mole, molecular weight of oxygen = 16 g/mole.

1.2 Vehicle CH_4 and N_2O emissions

EMFAC values were used to calculate fleet averaged CH_4 and N_2O emission factors for the whole light duty gasoline fleet. The Global Warming Potentials for CH_4 and N_2O are from IPCC guidelines and are GREET default values. The calculations are shown in Table 1.03.

Table 1.03 Vehicle CH_4 and N_2O Emissions (per MJ fuel).

Parameter	**Emissions factor (g/gal)**	**GWP**	**GHG (gCO_2e/MJ)**
N_2O	0.755	298	0.66
CH_4	0.266	25	0.16
Total			**0.82**